Review Article

# Anaesthesia Ventilators

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## ABSTRACT

Anaesthesia ventilators are an integral part of all modern anaesthesia workstations. Automatic ventilators in the operating rooms, which were very simple with few modes of ventilation when introduced, have become very sophisticated with many advanced ventilation modes. Several systems of classification of anaesthesia ventilators exist based upon various parameters. Modern anaesthesia ventilators have either a double circuit, bellow design or a single circuit piston configuration. In the bellows ventilators, ascending bellows design is safer than descending bellows. Piston ventilators have the advantage of delivering accurate tidal volume. They work with electricity as their driving force and do not require a driving gas. To enable improved patient safety, several modifications were done in circle system with the different types of anaesthesia ventilators. Fresh gas decoupling is a modification done in piston ventilators and in descending bellows ventilator to reduce th incidence of ventilator induced volutrauma. In addition to the conventional volume control mode, modern anaesthesia ventilators also provide newer modes of ventilation such as synchronised intermittent mandatory ventilation, pressure-control ventilation and pressure-support ventilation (PSV). PSV mode is particularly useful for patients maintained on spontaneous respiration with laryngeal mask airway. Along with the innumerable benefits provided by these machines, there are various inherent hazards associated with the use of the ventilators in the operating room. To use these workstations safely, it is important for every Anaesthesiologist to have a basic understanding of the mechanics of these ventilators and breathing circuits.

**Key words:** Anaesthesia ventilators, circle system changes, classification, hazards, working principle

## INTRODUCTION

The advent of automatic ventilators in the anaesthesia machine is a significant development in the practice of anaesthesia. During the earliest delivery of anaesthesia in 1846, a simple vaporization chamber was used, that required spontaneous ventilation by the patient to inhale air and diethyl ether.[1] Coxeters built HEG Boyle's original anaesthesia machine in 1917.[2] The early Boyle's machine had a breathing system comprising a Cattlin bag, three way stop cock and a facemask. Early anaesthesia machines had a breathing system which required the clinician to manually squeeze the reservoir bag to ventilate the patients. Blease invented pulmoflator, a simple bellows ventilator in 1945, which enabled automatic positive pressure ventilation for patients undergoing surgery.[3] This was followed by continued refinement with the Bird and Bennett ventilators two decades later.

The contemporary anaesthesia ventilators in the anaesthesia workstations by Dräger, Datex-Ohmeda and others integrate many advanced intensive care unit (ICU) – type ventilation features and can provide ventilation to the most challenging patients brought to the operating room. These anaesthesia ventilators have sophisticated computerised controls, have several modifications to the circle breathing system and can provide advanced types of ventilatory support. In this article, we will discuss the classification of anaesthesia ventilators, their working principle, ventilation modes in newer anaesthesia ventilators and various changes adopted in the circle system in the newer anaesthesia ventilators. We have also discussed various hazards

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associated with the use of ventilators in the operating room.

## CLASSIFICATION

Several methods of classification of ventilators exist. According to their mechanism of action ventilators can be classified as:

1. Mechanical thumbs.
2. Minute volume dividers.
3. Bag squeezers.
4. Intermittent blowers.

### Mechanical thumbs

This uses principle of T piece in providing ventilation. By rhythmical application of thumb to occlude the T piece, intermittent positive pressure ventilation is generated. In ventilators such as the Sechrist, the anaesthetist's thumb is replaced by a pneumatically operated valve, the cycling of which is determined by settings on ventilator controls.

### Minute volume dividers

In these types of ventilators, pressurised gas is fed into a ventilator system to be collected by a reservoir, which is continually pressurised by a spring, a weight or its own elastic recoil. It has one inspiratory valve and another expiratory valve, which are linked together and operated by a "bistable" mechanism. All driving gas that is supplied is delivered to the patient. For example if fresh gas flow delivered to patient is 10 L/min, this is delivered to patient as minute volume. However, it is divided into several inspiratory volumes of breaths depending on settings of volume and rate mechanism of ventilators e.g., 10 breaths of 1 L, 20 breaths of 0.5 L and so on. These ventilators are referred to as minute volume dividers since they just divide up intended minute volume supplied by the driving gas. Examples of minute volume dividers are East-Freeman® automatic vent, the Flomasta® and Manley MP3®.[4]

### Bag squeezers

This type of ventilator is usually employed in conjunction with a circle or Mapleson D system. Bellows may be squeezed pneumatically by placing it in a canister and feeding a driver gas in the space between canister and bellows or squeezed mechanically by means of a motor and suitable gears and levers or by a spring or a weight e.g., Manley servovent®, Penlon Nuffield 400® series ventilator, Ohmeda® 7800, Servo® 900 series, etc.

### Intermittent blowers

These ventilators are driven by a source of gas or air, at a pressure of 45-60 psi. The driving gas is normally delivered to patient undiluted, but it may be passed through a venturi device so that air, oxygen or anaesthetic gases may be added to it. e.g., Pneupac® and Penlon Nuffield® 200 series ventilator.[5]

Modern anaesthesia ventilators can also be classified based on the basis of power source, drive mechanism, circuit designation, cycling mechanism and type of bellows.[6,7]

#### *Power source*

Power source can be a compressed gas, electricity or a combination of both electricity and compressed gas. Older pneumatic ventilators required only a pneumatic power source to function properly. Contemporary electronic ventilators require either an electrical only or both an electrical and a pneumatic power source.

#### *Drive mechanism and circuit designation*

- Double circuit: Bellows ventilators.
- Single circuit: Piston ventilators.

#### Double circuit or bellows ventilators

Double circuit ventilators are most commonly used in modern anaesthesia workstations. These ventilators have bellows in box design. In these ventilators, a pressurised driving gas compresses bellows and bellows in turn deliver ventilation to patients. Driving gas will be outside bellows and the inside of bellows is connected to breathing system gas, thus forming a dual circuit. Examples of double circuit ventilators are Datex ohmeda® 7810, 7100, 7900, 7000; North American Drager AV-E® and AV-2+®.

#### Single circuit or piston ventilators

Piston ventilators (e.g., Apollo®, Narkomed 6000®, Fabius GS®) use a computer controlled motor instead of compressed gas to deliver gas in the breathing system. In these systems, instead of dual circuit with patient gas in one and driving gas in other, a single patient gas circuit is present.

#### *Cycling mechanism*

Most anaesthesia machine ventilators are time cycled and provide ventilator support in the control mode. Inspiratory phase is initiated by a timing device. Older pneumatic ventilators use a fluidic timing device. Contemporary electronic ventilators use a solid-state timing device and are classified as time cycled and electronically controlled.

### *Type of bellows*

The direction of bellows movement during the expiratory phase determines the bellows classification. Ascending (standing) bellows ascend during the expiratory phase, whereas descending (hanging) bellows descend during the expiratory phase. Most contemporary anaesthesia ventilators have ascending bellows design and are safer. Ascending bellows do not fill and tend to collapse when disconnection occurs.[8] However, the ventilator may continue to deliver small tidal volume.[9] The descending bellows continue their upwards and downwards movement even after disconnection. The driving gas pushes the bellows upwards during the inspiratory phase. During the expiratory phase, room air is entrained into the breathing system at the site of the disconnection because gravity acts on the weighted bellows. The disconnection pressure monitor and a volume monitor may not detect a disconnection.[10,11] Hence, it is difficult to detect any disconnection in a descending bellows ventilator.

Some newer anaesthesia systems (i.e., Dräger Julian® and Datascope Anestar®) have descending bellows to allow incorporation of fresh gas decoupling. An important safety feature on these descending bellows workstations is an integrated carbon dioxide apnoea alarm that cannot be disabled while the ventilator is in use.

## Working principles of a double circuit, ascending bellows ventilator

These ventilators consist of bellows, which are housed in a clear rigid plastic chamber. The bellows are analogous to the reservoir bag in the breathing circuit and they act as an interface between breathing system gas and ventilator driving gas. The driving gas circuit is located outside bellows and patient gas circuit inside bellows.

During inspiration, a driving gas, which is a pressurised oxygen or air from the ventilator power outlet (45-50 psig) is routed to the space between inside wall of plastic chamber and outside wall of bellows increasing the pressure inside the chamber. This causes pressure to be exerted on bellows causing it to be compressed and the anaesthetic gases inside the bellows are delivered to the patient. This compression action is analogous to a hand of an anaesthesiologist squeezing the reservoir bag.[12] At the same time, the ventilator relief valve which vents excess gas to scavenging system and exhaust valve, which vents driving gas to the atmosphere are closed.

During expiration, the bellows re-expands as breathing system gases flow into it. Driving gas is vented to the atmosphere through the exhaust valve. After the bellows are fully expanded, excess gases from the breathing system are vented to scavenging system through ventilator relief valve. Thus, excess gases are vented during expiration in contrast to manual ventilation, when they are vented during inspiration. The ventilator relief valve or spill valve has a minimum opening pressure of 2-4 cm of $H_2O$ with ascending bellows design.[13] This enables the bellows to fill during expiration. This causes all ascending bellows ventilators to produce 2-4 cm of $H_2O$ positive end-expiratory pressure (PEEP) within the breathing circuit.

## Working principle of a single circuit, piston ventilator

Piston ventilators use an electric motor to compress gas in the breathing circuit, creating the motive force for mechanical ventilator inspiration to proceed. The motor's force compresses the gas within the piston, raising the pressure within it, which causes gas to flow into the patient's lungs.

The piston ventilator design is uniquely suited to deliver tidal volume accurately.[14] Since the area of the piston is fixed, the volume delivered by the piston is directly related to the linear movement of the piston. When the user sets a volume to be delivered to the patient, the piston moves the distance necessary to deliver the required volume into the breathing circuit. Furthermore, since the connection between the piston and the driver motor is rigid, the position of the piston is always known and the volume delivered by the piston is also known. Sophisticated computerised controls in these ventilators are able to provide advanced types of ventilator support such as synchronised intermittent mandatory ventilation (SIMV), pressure-controlled ventilation (PCV) and pressure-support ventilation (PSV) in addition to the conventional control-mode ventilation.

### *Advantages of a piston ventilator*

- Quiet.
- No PEEP (2-3 cm water are mandatory on standing bellows ventilators due to the design of the ventilator spill valve).
- Greater precision in delivered tidal volume due to compliance and leak compensation, fresh gas decoupling and the rigid piston design. There are less compliance losses with a piston as compared with a flexible standing bellows compressed by driving gas.

- Electricity is the driving force for the piston and so there is no requirement of a driver gas to deliver ventilation.
- The ability to deliver volume accurately using pressure sensors is a unique advantage of the piston ventilator. Pressure sensors are simple devices that are easily calibrated and can be located anywhere in the breathing system since the plateau pressure is essentially constant throughout. Control of the bellows ventilator based upon pressure measurement is difficult due to variable compression of the drive gas from patient to patient.

#### *Disadvantages of a piston ventilator*

- Loss of the familiar visible behaviour of a standing bellows during disconnections.
- Quiet and less easy to hear regular cycling.

### Bag/ventilator switch

Whenever a ventilator is used on an anaesthesia machine, the circle system's adjustable pressure limiting (APL) valve must be functionally removed or isolated from the circuit. A bag/ventilator switch generally accomplishes this. When the switch is turned to "bag" the ventilator is excluded and spontaneous/manual (bag) ventilation is possible. When it is turned to "ventilator," the breathing bag and the APL valve are excluded from the breathing circuit. The APL valve may be automatically excluded in some newer anaesthesia machines when the ventilator is turned on.

### Fresh gas decoupling

Fresh gas decoupling is a feature adopted in circle systems of some newer anaesthesia workstations using either piston or descending bellows ventilators. In a traditional circle system fresh gas inflow is coupled directly into the circle system and the total volume delivered to the patient's lung is the sum of volume delivered from the ventilator plus the volume of gas that enters through fresh gas inlet.[12] In contrast when fresh gas decoupling is used, fresh gas is diverted. During the inspiratory phase, the fresh gas coming from the anaesthesia work station via fresh gas inlet is diverted into a reservoir bag by a decoupling valve, located between fresh gas source and ventilator circuit. The reservoir bag serves as accumulator for fresh gas until expiration phase begins. During expiration phase, decoupling valve opens to allow accumulated fresh gas in reservoir bag to be drawn into circle system to refill the piston ventilator chamber or descending bellows. The ventilator exhaust valve also opens during the expiratory phase and excess fresh gas and expired patient gas escape into scavenging system. Fresh gas decoupling is used in machines like Drager Narkomed 6000®, Fabius GS®, etc.

#### *Advantages of fresh gas decoupling*

Decreased volutrauma or barotrauma in the event of inappropriate use of oxygen flush or increased fresh gas flow.

#### *Disadvantages of fresh gas decoupling*

There is a possibility of entrainment of room air into patient circuit when either fresh gas flow is inadequate or reservoir bag is removed or improperly fit and this may result in patient awareness or hypoxia.

### Ventilation modes in anaesthesia ventilators

Earlier anaesthesia ventilators used in the operating room were simpler than their ICU counterparts with fewer basic modes of ventilation. However, with the increasing number of critically ill-patients getting operated, there was an increasing demand for newer sophisticated modes of ventilation. With improvement in technology, newer anaesthesia machines have adopted many new ventilator modes.

### Volume control ventilation

All ventilators offer volume control (VC) mode. In this mode, the preset volume is delivered with a constant flow [Figure 1]. Peak inflation pressure varies with patient's compliance and airway resistance. Volume is adjusted to avoid atelectasis and respiratory rate adjusted for reasonable end tidal carbon dioxide while monitoring peak inflation pressure. Modern anaesthesia ventilators can deliver tidal volume in the range of 20-1500 ml.

Typical ventilator settings in VCV:

- Tidal volume: 6-10 ml/kg body weight.
- Rate: 8-12 breaths/min.
- PEEP: 0-5 cm $H_2O$ to start with and titrated.

### Pressure-controlled ventilation

In PCV, inspiratory pressure is maintained constant and the tidal volume is allowed to vary. Inspired volume varies according to changes in compliance and airway resistance. Flow is high at first to produce the set pressure early in inspiration and it is less later in inspiration to maintain the set pressure throughout the inspiratory time (decelerating flow pattern) [Figure 2]. Target pressure is adjusted to produce a reasonable tidal volume to avoid the extremes of atelectasis and volutrauma. Rate

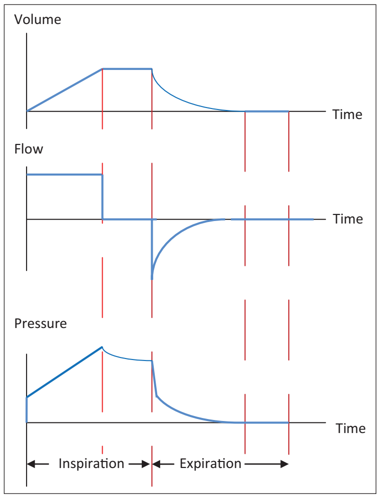


**Figure 1:** Ventilator waveforms volume control ventilation

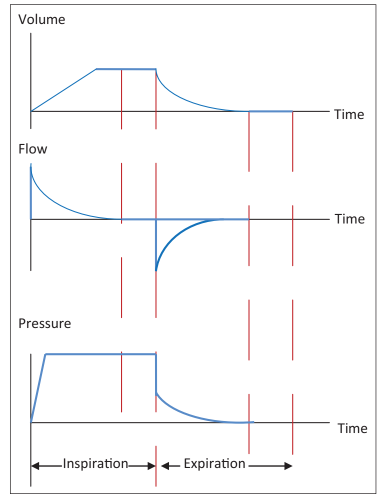


**Figure 2:** Ventilator waveforms pressure control ventilation

is adjusted to a reasonable end-tidal carbon dioxide. PCV has been found to improve oxygenation in laparoscopic obesity surgeries when compared to VCV.[15] PCV mode is also useful in neonatal surgeries, in pregnancy and in patients with acute respiratory distress syndrome.

### PCV volume guaranteed

It is a new mode in which ventilator operates as in PCV mode, but a tidal volume target is also set. PCV-VG mode delivers uniform tidal volume with all the benefits of PCV. It helps to ensure that the patient receives the uniform tidal volume regardless of compliance changes caused by packs, retractors, position, surgical exposure or relaxation.

The ventilator delivers the preset tidal volume with low pressure using a decelerating flow. The first breath delivered to the patient is a volume-controlled breath. The patient's compliance is determined from this volume breath and the inspiratory pressure level is then established for the subsequent PCV-VG breaths. PCV-VG breaths are characterised by a decelerating flow and a square pressure waveform.

### Synchronised intermittent mandatory ventilation

SIMV is designed to provide assured rates and tidal volumes in a manner that supplements the patient's own spontaneous efforts. By synchronising with the patient's effort, the ventilator responds to the patient's breathing needs.

SIMV allows the ventilator to sense the patient's own breathing and permit spontaneous breathing between mechanical ventilations while providing sufficient mandatory breaths should the patient's own rate fall below a preset value.

Because of the synchronization provided in SIMV mode, the ventilator will assist a patient's own breath when that breath falls within the synchronization window as specified by the clinician. These synchronised ventilations can help overcome difficulties experienced when patients attempt to compete with controlled mechanical ventilation.

During the course of general anaesthesia, various agents such as narcotics, inhalation agents, neuromuscular blocking agents and sedatives can affect the overall respiratory rate and tidal volume. The application of SIMV is well suited to manage these situations. SIMV can be applied either in volume control (SIMV-VC) or SIMV-pressure control mode.

### Pressure-support ventilation

PSV is particularly useful for patients maintained in spontaneous respiration under general anaesthesia.[16,17] With the advent of the supraglottic devices such as laryngeal mask airway (LMA) and I- gel, spontaneous breathing is much more commonly maintained during general anaesthesia. However, it is difficult to maintain a light enough plane of anaesthesia to permit spontaneous ventilation while retaining sufficient depth for surgery to proceed. PSV mode in modern anaesthesia ventilators is useful in this regard.

PSV is patient triggered and either time or flow cycled. In PSV, ventilator supports spontaneous breathing by applying pressure to airway in response to patient's supported breaths. During PSV once a breath is initiated, the ventilator pressurises the airway to a given inspiratory support pressure. This pressure is usually from 5 cm to 10 cm $H_2O$ and provides the additional ventilatory support required to offset the effects of general anaesthesia. Each PSV assisted breath is terminated according to a preset decrease in flow or after a specific duration, as a backup. By applying pressure to the airway immediately upon sensing a patient breath, PSV enhances inspiratory flow and provides improved gas distribution within the lungs. This enhanced gas distribution results in a lower peak airway pressures, which is quite advantageous when LMAs are used. Lower pressure results in less gas leakage around LMA seal.

PSV reduces the patient's work of breathing during spontaneous respiration and counters the reduction in functional residual capacity, produced due to inhalational agents. Some ventilators have an apnoea backup feature to provide ventilator breaths when there is no spontaneous effort (PSV-pro).

## Circle system variations in some newer anaesthesia work stations

### *Datex Ohmeda S/5® anaesthesia delivery unit (ADU)*

It has pneumatic, double circuit ascending bellows with microprocessor control. Principal difference in the ADU's circle system is the "D" Lite flow and pressure transducer fitted in the circle system at the level of Y connector. On most traditional circle systems, exhaled tidal volume is measured by a spirometry sensor placed in proximity to expiratory valve. Placement of D lite sensor at Y connector provides better location for measuring exhaled tidal volume, allows monitoring of airway gas composition and pressure to be done with a single adapter and provides the ability to analyse both inspiratory and expiratory airflow to generate complete flow - volume spirometry. Fresh gas inlet is moved to patient side of inspiratory valve without adversely effecting exhaled tidal volume measurement.

### *Drager medical Narkomed 6000® series, Fabius GS® and Apollo® work stations*

The ventilators of these systems may be classified as electrically powered, piston driven, single circuit, electronically controlled with fresh gas decoupling. The circle systems used by the Drager workstations use fresh gas decoupling feature by incorporating a decoupling valve located between fresh gas source and ventilator circuit. Fresh gas decoupling system in Narkomed 6000® series use a reservoir bag for collection of fresh gas while Drager Fabius GS® and Apollo® workstation do not use breathing bag as a reservoir for fresh gas and have an alternative location for collection of fresh gas during inspiration.

## Ventilator alarms

Disconnection alarms are the most important and should be passively activated whenever a ventilator is used. Anaesthesia workstations should have at least three disconnect alarms: Low peak inspiration pressure, low exhaled tidal volume and low exhaled carbon dioxide. Other built in alarms include high peak inflation pressure, high PEEP, low oxygen supply pressure and negative pressure.

## Problems associated with mechanical ventilators in the operating room

### *Breathing circuit disconnection*

Breathing circuit disconnections and misconnections are the leading cause of critical events in anaesthesia.[18] Pneumatic and electronic pressure monitors and respiratory volume monitors are helpful in diagnosing disconnections. Factors that influence monitor effectiveness include disconnection site, location of the pressure sensor, threshold pressure alarm limit, inspiratory flow rate and resistance of disconnected breathing circuit.[19,20] Carbon-di-oxide monitors are probably best devices for revealing patient disconnection. An acute decrease or absence of measured end tidal carbon dioxide can occur due to circuit disconnection.

### *Ventilator fresh gas flows coupling*

Since the ventilator's spill valve is closed during inspiration, fresh gas flow from the machine's common gas outlet normally contributes to the tidal volume delivered to the patient. Thus, increasing fresh gas flow increases tidal volume, minute ventilation and peak inspiratory pressure. To avoid problems with ventilator-fresh gas flow coupling, airway pressure and exhaled tidal volume must be monitored closely and excessive fresh gas flows must be avoided.

### *High airway pressure*

Intermittent or sustained high inspiratory pressures during positive-pressure ventilation increase the risk of pulmonary barotrauma and/or hemodynamic compromise during anaesthesia. Excessively high pressures may arise from incorrect settings on the ventilator, ventilator malfunction, fresh gas flow coupling or activation of the oxygen flush during the inspiratory phase of the ventilator.[21] Use of the oxygen flush valve during the inspiratory cycle of a ventilator must be avoided because the ventilator spill valve will be closed and the APL valve is excluded; the surge of oxygen and circuit pressure will be transferred to the patient's lungs.

### *Bellows assembly problems*

Leaks can occur in bellows assembly. Improper seating of plastic bellows housing can lead to escape of driving gas leading to hypoventilation.[22,23] A hole in bellows can lead to alveolar hyperinflation and barotrauma since high pressure driving gas can enter into patient circuit. Oxygen concentration of patient gas may increase if driving gas is 100% oxygen or it may decrease if the driving gas is composed of gas-oxygen mixture.[24-26] Decrease in the concentration of inspired anaesthetic gases may lead to intra-operative awareness.[25] Ventilator relief valve incompetency leads to hypoventilation. Relief valve incompetency can occur due to disconnected pilot line, ruptured valve or a damaged flapper valve.[27-31]

### *Tidal volume discrepancies*

Large discrepancies between the set and actual tidal volume that the patient receives are often observed with anaesthesia ventilators during VCV. Causes include breathing circuit compliance, gas compression, ventilator-fresh gas flow coupling and leaks in the anaesthesia machine, the breathing circuit, or the patient's airway.

Several mechanisms have been built into newer anaesthesia machines to reduce tidal volume discrepancies due to circuit compliance. During the initial electronic self-checkout, some machines measure total system compliance and subsequently use this measurement to adjust the excursion of the ventilator bellows or piston; leaks may also be measured but are usually not compensated. The actual method of tidal volume compensation or modulation varies according to manufacturer and model.

### *Power supply problems*

As anaesthesia workstations are becoming more dependent on integrated computer controlled systems, power interruptions become more significant. Battery backup systems are designed to continue operation for up to several hours after a power failure. Even in these systems certain time period is required for rebooting after an outage has occurred.

### *Ventilator turned off*

There may be instances when the ventilator is needed to be turned off transiently such as during some radiological procedures to reduce movement. The operator may forget to turn it on. Some ON/OFF ventilator switches can be placed in an intermediate position. The potential exists for reverting to off position with only a slight impact.[32]

## SUMMARY

Anaesthesia ventilators have become an integral part of all modern anaesthesia workstations. With the improvement in technology, they have become more sophisticated and provide most of the advanced features seen in ICU ventilators. It is essential for the anaesthesiologist to have a thorough understanding of the functioning of these ventilators to use them safely in the operating room.

## REFERENCES

1. Desbarax P. Morton's design of the early ether vaporisers. Anaesthesia 2002;57:463-9.
2. Abraham A. Trade names that have become generic names in anaesthesia. Indian J Anaesth 2012;56:411-3.
3. McKenzie AG. The inventions of John Blease. Br J Anaesth 2000;85:928-35.
4. Jones PL, Hillard EK. The flomasta. A new anaesthetic ventilator. Anaesthesia 1977;32:619-25.
5. Adams AP, Henville JD. A new generation of anaesthetic ventilators. The pneupac and penlon A-P. Anaesthesia 1977;32:34-40.
6. Spearman CB, Sanders HG. Physical principles and functional designs of ventilators. In: Kirby RR, Smith RA, Desautels DA, editors. Mechanical Ventilation. New York: Churchill Livingstone; 1985. p. 59.
7. McPherson SP, Spearman CB. Introduction to ventilators. In: McPherson SP, Spearman CB, editors. Respiratory Therapy Equipment. 3rd ed. St. Louis: C.V. Mosby; 1985. p. 230.
8. Blackstock D. Advantages of standing bellows ventilator and low flow techniques. Anaesthesiology 1984;60:167.
9. Gravenstein JS, Nederstigt JA. Monitoring for disconnection: Ventilators with bellows rising on expiration can deliver tidal volumes after disconnection. J Clin Monit 1990;6:207-10.
10. Sinclair A, van Bergen J. Flow resistance of coaxial breathing systems: Investigation of a circuit disconnect. Can J Anaesth 1992;39:90-4.
11. Russell WJ, Webb RK, Van der Walt JH, Runciman WB. The Australian incident monitoring study. Problems with ventilation: An analysis of 2000 incident reports. Anaesth Intensive Care 1993;21:617-20.
12. Dorsch JA, Dorsch SE. Anaesthesia ventilators. In: Dorsch JA, Dorsch SE, editors. Understanding Anaesthesia Equipment. 4th ed. Baltimore: Williams and Wilkins; 1999. p. 310.
13. Andrews JJ. Understanding your anaesthesia machine and ventilator. Review Course and Lectures. Cleveland, OH: International Anaesthesia Research Society; 1989. p. 59.
14. Bachiller PR, McDonough JM, Feldman JM. Do new anesthesia ventilators deliver small tidal volumes accurately during volume-controlled ventilation? Anesth Analg 2008;106:1392-400.
15. Cadi P, Guenoun T, Journois D, Chevallier JM, Diehl JL, Safran D. Pressure-controlled ventilation improves oxygenation during laparoscopic obesity surgery compared with volume-controlled ventilation. Br J Anaesth 2008;100:709-16.
16. Christie JM, Smith RA. Pressure support ventilation decreases inspiratory work of breathing during general anesthesia and spontaneous ventilation. Anesth Analg 1992;75:167-71.

17. Brimacombe J, Keller C, Hörmann C. Pressure support ventilation versus continuous positive airway pressure with the laryngeal mask airway: A randomized crossover study of anesthetized adult patients. Anesthesiology 2000;92:1621-3.
18. Cooper JB, Newbower RS, Kitz RJ. An analysis of major errors and equipment failures in anesthesia management: Considerations for prevention and detection. Anesthesiology 1984;60:34-42.
19. Raphael DT, Weller RS, Doran DJ. A response algorithm for the low-pressure alarm condition. Anesth Analg 1988;67:876-83.
20. Slee TA, Pavlin EG. Failure of low pressure alarm associated with the use of a humidifier. Anesthesiology 1988;69:791-3.
21. Roth S, Tweedie E, Sommer RM. Excessive airway pressure due to a malfunctioning anesthesia ventilator. Anesthesiology 1986;65:532-4.
22. Feeley TW, Bancroft ML. Problems with mechanical ventilators. Int Anesthesiol Clin 1982;20:83-93.
23. Lee K, Jelenich S, Henry E. Leak of driving gas from Air-Shields ventilator. Can Anaesth Soc J 1986;33:263-4.
24. Podraza A, Salem MR, Harris TL, Moritz H.Effects of bellows leaks on anaesthesia ventilator function. Anesth Analg 1991;72:S215.
25. Baraka A, Muallem M. Awareness during anaesthesia due to a ventilator malfunction. Anaesthesia 1979;34:678-9.
26. Longmuir J, Craig DB. Inadvertent increase in inspired oxygen concentration due to defect in ventilator bellows. Can Anaesth Soc J 1976;23:327-9.
27. Khalil SN, Gholston TK, Binderman J, Antosh S. Flapper valve malfunction in an Ohio closed scavenging system. Anesth Analg 1987;66:1334-6.
28. Sommer RM, Bhalla GS, Jackson JM, Cohen MI. Hypoventilation caused by ventilator valve rupture. Anesth Analg 1988;67:999-1001.
29. Eisenkraft JB. Potential for barotrauma or hypoventilation with the Dräger AV-E ventilator. J Clin Anesth 1989;1:452-6.
30. Wyant GM, Craig DB, Pietak SP, Jenkins LC, Dunn AJ. Safety in the operating room. Can Anaesth Soc J 1984;31:287-301.
31. Choi JJ, Guida J, Wu WH. Hypoventilatory hazard of an anesthetic scavenging device. Anesthesiology 1986;65:126-7.
32. Ciobanu M, Meyer JA. Ventilator hazard revealed. Anesthesiology 1980;52:186-7.

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Announcement

## FAMILY BENEVOLENT FUND OF ISA

Family Benevolent Fund (FBF) is one of the welfare programs of Indian Society of Anaesthesiologists (ISA). It is registered under the Societies Registration Act. Please visit the website www.isafbf.com. Membership is limited only to ISA members and President and Secretary are in the executive body of FBF. ISA member can be a member of FBF by paying the Membership fee depending on the age of members.

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|---|---|---|
| Up to 35 years | - | 3,000/- |
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Age proof is required, the membership fee increased from April 2010. Immediate settlement of Fraternity amount to the nominee, in case of death of a member. So far 14 members were supported with an amount of Rs. 18 Lakhs.

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